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Principal features of Chornohora climate (Ukrainian Carpathians)

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Abstract. Chornohora is the highest mountain ridge in the Ukrainian Carpathians with 6 peaks of an altitude over 2,000 m above sea level (Hoverla is the highest peak, 2,061 m a.s.l). its climate is explored less than other mountain ridges in Europe. The massif is a climatic barrier for air masses on NW-SE line. To describe the climate of this area data from the weather station at Pozhyzhevska alpine meadow for the years 1961-2010 were used. The seasonal and long-term variability of air temperature, atmospheric precipitation and snow cover were investigated on the background of air circulation types. The results show that general features of Chornohora climate depend both, on elevation above sea level and on air circulation. Lowest temperature is observed at N-NE circulation and highest precipitation – at western air inflow. Long-term changes of examined climate elements in Chornohora show significant increase in mean (0.13°/10 years) and minimum (0.22°C/10 years) air temperature as well as in snow cover depth and number of snowy days.

Key words:
Chornohora,
Eastern Carpathians,
air circulation,
mountain climate,
climate changes

Introduction

First sporadic climate researches in Chornohora region were organized by initiative of the Polish Tatras Society, in 1870s. Regular meteorological observations at the Botanical and Agricultural Station at Pozhyzhevska alpine meadow were started in 1899. The measurements were made three times a day during vegetation period (June-September) and included: air temperature, vapour pressure, relative humidity, evaporation, precipitation, atmospheric pressure, soil temperature, wind speed and direction, cloud cover as well as actinometric and heliographic observations (Dworak and Rymarowicz 1992). The station worked until 1939. The results were published in yearbooks of "Kosmos" journal (Szulc 1911, 1912). However, the information about solar radiation and sunshine duration in Chornohora were reported by Stenz (1925, 1926, 1929).

The new impulse for meteorological measurements in Chornohora gave the High-Mountain Meteorological and Astronomical Observatory (HMAO) which was opened on July 29, 1938 at the top of Mt Pip Ivan (Mt Popivan), currently 2028 m a.s.l. The observatory was a part of weather station's network of the former National Meteorological Institute and was equipped with very modern meteorological instruments typical for the first category station (over 20 self-recording instruments and about 30 manual devices, see Skrynyk and Rymarowicz 2018). The scientific program in the field of meteorology, climatology and geophysics included studies on air currents, high-altitude inversions (both temperature and precipitation), heat transfer and ionization of the atmosphere (Kreiner and Rymarowicz 1992). The work of HMAO was interrupted by outbreak of the Second World War. To the present days, there are preserved data sheets of Meteorological Observations Results (MOR) for 10 months (from October 1938 until July 1939). The MOR sheets contain results of standard meteorological observations made three times a day. They were fortunately founded in private collections and presented by Skrynyk and Rymarowicz (2018). History of the beginning of observations at Mt Pip Ivan was presented by Kreiner (1989), Kreiner and Rymarowicz (1992), Rymarowicz and Wielocha (2012) as well as by Rymarowicz and Kreiner (2012).

In 1959 meteorological observations at Chornohora were undertaken in the High Mountain Biological Station (1429 m a.s.l.) of the Ukrainian National Academy of Sciences at Pozhyzhevska alpine meadow. The weather station was located at the altitude of 1451 m a.s.l. (610 m below the highest peak of Mt. Hoverla) and meteorological measurements are conducting eight times a day until now.

Starting from 1978 periodical meteorological measurements are also carried out at the Chornohora Geographical Station of the University of Lviv (985 m a.s.l.). Periodical character of observations do not allow for complex analysis of climate of northern part of Chornohora. However, based on these observations Petlin and Matviyiv (2003) have elaborated elevational diversity gradient (EDG) and altitudinal climate zones (ACZ) of Chornohora. The EDG for winter is -0.3°C per 100 m, for summer -0.6°C, and mean annual -0.47°C/100 m. Four ACZ were distinguished, namely: moderately cool (450-850 m a.s.l. with a sum of active temperatures above +10°C equal to 1750 degrees), cool (850-1250 meters a.s.l., sum of active temperatures 1000-1750 degrees), moderately cold (1250-1500 m a.s.l., sum of active temperatures 600-1000 degrees) and cold (above 1500 m a.s.l., sum of active temperatures below 600 degrees). Different vertical climatic zones (VCZ) were proposed for Eastern Carpathians by Niedźwiedź (2012) based of vertical variability of mean annual temperature developed by Hess (1965). Areas below 850 m a.s.l with annual air temperature (Ta) >+6°C are there classified as moderately warm. Moderately cool are slopes 850-1200 m a.s.l. (Ta from +6 to +4°C). Areas elevated 1200-1550 m a.s.l. are classified as cool (Ta from +4°C to +2°C), belt of 1550-1850 m a.s.l. is very cool zone (Ta from +2°C to 0°C) and the areas >1850 m are moderately cold (Ta<0°C).

In Chornohora there were also carried out short term climatic research and for some parts of the massif topoclimates were recognised (Kotarba 2006; Shuber 2013; Mukha 2017). General overview of the Carpathians climate (including Chornohora) can be found in the research based on CARPATCLIM Project (Cheval et al. 2014; Spinoni et al. 2014). The project presents spatial distribution of different climate elements with various temporal steps (daily, monthly, yearly and multiannual). Climate data cover the period 1961-2010. The essential climatic characteristics can be also find in papers of Buchinskij et al (1971) and Niedźwiedź (2012).

The measurements and research listed above did not provide detail description of Chornohora climate. Therefore, the first aim of the present study is to characterize seasonal and multiannual variability of essential climate elements of Chornohora, namely: air temperature, precipitation and snow cover. The second aim of research is to verify whether climate elements in Chornohora are influenced by air circulation.

Materials and methods

The materials used in the study come from weather station at Pozhyzhevska alpine meadow (P, 1451 m a.s.l.) and were obtained from the archive of the Central Geophysical Observatory of Ukraine. Daily data of air temperature (mean - TM, minimum - TN and maximum - TX), precipitation (RR) and snow depth (SD) for the years 1961-2010 were available. Completeness of data is - 99.7%.

Location of Pozhyzhevska station determines the coordinates: φ 48°09´14"N and λ 24°32´03"E. It is located on north-eastern slope of the main ridge of Chornohora massif. The station is situated on the flattening, within lateral ridge that extends from the top of Mt Pozhyzhevska (1822 m a.s.l.). The weather station is located in the zone of moderately cold climate over a grassy meadow with single trees. The nearest forest edge is situated about 50 m SW from the station.

Chornohora mountain ridge represents the Dfc Köppen-Geiger climate zone (boreal, with cool summer and without dry season) within altitudinal belt of 1380-1880 m a.s.l. (Kottek et al. 2006; Rubel et al. 2017). According to Hess (1965) and Niedźwiedź (2012) Pozhyzhevska station represents the climate conditions of the cool vertical climatic zone of Eastern Carpathians.

To verify how air circulation influence climate features of Chornohora the classification by Niedźwiedź was applied (Niedźwiedź 1993, 2019). The classification is fully represented for northern Carpathians within the area of 49-51°N and 18-24°E. While the Chornohora is located very close to eastern border of air classification area the author assumed it well represents the studied mountain massive. The Niedźwiedź classification covers the period from 1873 up to the present days and give daily information of prevailing air advection (with 21 or 11 categories) and air mass (Table 1).

Based on daily meteorological data for Pozhyzhevska station the characteristics of monthly, seasonal and annual air temperature (mean – TM, average minimum – TN, lowest minimum – TNabs, average maximum – TX and highest maximum - TXabs), number of days with specific air temperature (hot – TX>25°C, very cold – TX<0°C, frosty – TN<-10°C, very frosty – TX<-10°C), precipitation (totals – RR, rainy days – RRdays, days with precipitation more than 10 mm – RR>10 and days with precipitation more than 30 mm – RR>30) and snow cover (mean depth – SD, maximum depth – SDmax, days with snow cover – SDdays and days with snow cover more than 10 cm – SD>10) were determined. Daily, monthly and annual amplitudes of air temperature (DT) were also calculated, as a difference between highest maximum and lowest minimum temperature. The 50 years trends in seasonal and annual values of studied climate characteristics were defined as well.

To explain how air circulation influence the values of examined climate variables and their long-term changes we have calculated complex circulation indicators: P – of west-east air inflow, S – of south-north air inflow and C – of cyclonic-anticyclonic circulation. In this purpose Murray-Lewis (1966) method was applied (Niedźwiedź 1993). The indicators are calculated as follows:

The individual daily indices for particular advection categories (*Pi*, *Si*, *Ci*) are shown in Table 2.

The high positive annual values of *P* index represent years with great predominance of western air inflow and the negative ones – eastern inflow. Positive values of *S* index tell about south air inflow and

Table 1. Description of air masses and air circulation types according to Niedźwiedź classification

Air circulation types		Air mass
Anticyclonic situations (1—10):	Cyclonic situations (11—20):	PA - arctic
Na — North	Nc — North	PPm - polar maritime
NEa — North–East	NEc — North–East	PPms - polar maritime transformed
Ea — East	Ec — East	PPmc - polar maritime warm
SEa — South–East	SEc — South–East	PPk - polar continental
Sa — South	Sc — South	PZ - tropical
SWa — South–West	SWc — South–West	mp - not defined
Wa — West	Wc — West	
NW — North–West	NWc — North–West	
Ca — central anticyclone situation (high center)	Cc — central cyclonic, center of low	
Ka — anticyclonic wedge or ridge of high pressure	Bc — through of low pressure (different directions of air flow and frontal system in the axis of through)	
x — unclassified situation		

Source: Niedźwiedź (2019)

Table 2. Individual daily indices of advection categories in particular circulation indicators

Circulation indicator	Advection	Individual daily indices
	W	Pi = +2
P	NW, SW	Pi = +1
(west-east inflow)	NE, SE	Pi = -1
	others	Pi = 0
	S	Si = +2
	SW, SE	Si = +1
S	NW, NE	Si = -1
(south-north inflow)	N	Si = -2
	others	Si = 0
	Cc, Bc	Ci = +2
C	other cyclonic	Ci = +1
(cyclonic-anticyclonic circulation)	Ca, Ka	Ci = -2
	other anticyclonic	Ci = -1

Source:Niedźwiedź (1993)

the negative ones – northern inflow. Positive *C* index values inform about predominance of cyclonic, and negative ones – about anticyclonic circulation.

The STATGRAPHICS Centurion XVI software package was used in statistical analysis.

Results

General characteristics of Chornohora climate

Air circulation is one of the most important factors which influence meteorological and weather conditions. In northern Carpathians in general in about 51% of days a year prevail anticyclonic circulation and in almost 48% days – cyclonic one. The most frequent are Ka (12%, anticyclonic wedge or ridge of high pressure) as well as Wc (west cyclonic) and Bc (through of low pressure), both of about 10% days a year. Relatively frequent (about 8%) is also west anticyclonic (Wa) circulation. In general, advection of air from western sector is observed in about 38% days a year.

The mean annual air temperature at Pozhyzhevska weather station is 2.8°C. The coldest months are January and February with TM of -6.2°C and -6.0°C, respectively, and the hottest ones are July (11.8°C) and August (11.9°C). Mean monthly TN varies from -8.7°C in January to 9.3°C in August and mean monthly TX fluctuates from -3.5°C in January to 15.3°C in August Lowest minimum temperature was recorded on January 17, 1963 (-28.5°C) in polar continental air mass during cyclonic circulation from north (Nc). Very low temperatures (<-25°C) were registered also in December, February and March within arctic air mass during advection of air from north (Nc) and north-east (NEa) or at anticyclonic wedge or ridge of high pressure (Ka). Highest maximum temperature was observed on August 3, 1998 (27.6°C) in tropical air mass during Bc advection (through of low pressure) (Table 3).

Hot days (TX >25°C) at Pozhyzevska are observed only in July and August. In total only 18 such days occurred in the studied period (0.4 day per year). 14 hot days were registered after the year

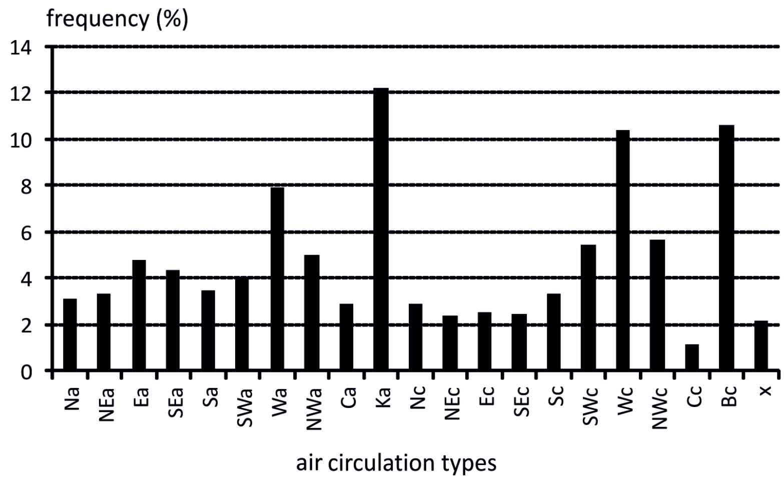

Fig. 1. Frequency of various air circulation types, according to Niedźwiedź classification, 1961-2010

1997. Longest hot period (6 days) was observed from 18 to 23 July 2007. It was characterised by Ka and Bc circulation types.

Very frosty days (TX <-10°C) occurs in average 9.3 times per year. Very frosty days were observed during whole 50 studied years. Longest period with such temperature lasted 17 days and was registered from 13 to 31 January 1963 at air advection mainly from N, NE and E or at anticyclonic wedge or ridge of high pressure.

For the studied period perennial amplitude of air temperature (DT) is 56.1°C (Table 2). The smallest values of this characteristic are observed in July (27.1°C) and August (27.5°C), while the greatest in January (38.2°C) and March (41.1°C).

The average annual totals of precipitation is 1448.2 mm. In yearly course maximum rainfall occurs in July (181.3 mm), and minimum in January (76.4 mm). Average precipitation totals for summer (JJA) is 489.5 mm (i.e. 33.8% of yearly value), for spring (MAM) 359.1 mm (24.8%), for autumn (SON) 330.4 mm (22.8%) and for winter (DJF) 269.2 mm (18.6%). Highest daily rainfall at Pozhyzhevska occurred on March 5, 2001 (116.9 mm) during Na advection. Daily precipitation above 90 mm was also recorded in May, at NWc, and in June, at NEc advection (Table 4).

At Pozhyzhevska station, the mean annual number of days with precipitation is about 189. Most rainy days occur in June (18.2) and July (18.1), while the least in September (13.3) and in October (13.1). In the studied period 48 days per year with precipitation ≥10 mm and about 6 days per year with precipitation ≥30 mm were noted in average. In the annual course majority of days with heavy rains are observed in the warm half year (May-October), more often in June and July (Table 5).

An important element of mountain climate is snow cover. At Pozhyzhevska alpine meadow its mean yearly value is only 12.5 cm. The highest mean monthly depth of snow cover (SDmean) occurs in March (30.9 cm) and February (29.2 cm). The maximum snow depth (SDmax) was observed in March, 1996 (134 cm). There is in average 158 days per year with snow cover and 95 days yearly with snow depth more than 10 cm. In the period December-March snow cover at Pozhyzhevska alpine meadow lasts for almost whole months and only single days without snow occurred in separate years. Majority of days with snow over 10 cm is noted in JFM (about 20), as well as in December and April – 14-18 days monthly (Table 6).

Climate Changes

During the studied period in the northern Carpathians have occurred changes in atmospheric circulation. The greatest changes were observed in case of C and P index. While in the first 20 years cyclonic inflow predominated than after 1981 more frequent was anticyclonic inflow of air. When con-

Table 3. Essential characteristics of air temperature at Pozhyzhevska weather station, 1961-2010

Characteristic	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
mean TM, °C	-6.2	-6.0	-3.4	1.8	7.2	10.2	11.8	11.9	8.0	4.1	-0.7	-4.8	2.8
average TN, °C	-18.1	-17.4	-14.3	-8.1	-2.5	1.3	3.8	3.6	-1.1	-7.0	-11.7	-16.4	-7.3
average TX, °C	4.7	4.8	8.6	12.9	18.4	20.6	22.1	22.4	18.6	15.9	10.6	5.9	13.8
lowest TN, °C	-28.5	-26.2	-26.0	-13.2	-8.4	-5.0	-0.6	0.1	-7.3	-13.6	-18.5	-25.4	-28.5
day, year	17,1963	06,1965	04,1987	07,1978	02,2007	07,1962	05,1984	25,1980 29,1981	28,1977	29,1997	29,1989	15,1961	1963-01-17
CT/AM	Nc/PPk	NEa/PA	Ka/PA	Ka/PA	Ca/PA	Na/PA	NWa/PA	Wa/PPm; NWc/PA	Ca/PA	Ka/PPm	Ca/PA	Nc/PA	Nc/PPk
highest TX, °C	9.7	11.1	15.1	19.0	22.0	24.7	26.5	27.6	23.5	21.0	16.1	11.4	27.6
day, year	16,1997 18,1999	03,2002	19,1990	24,1968	30,2005	29,1963	31,2005	03,1998	07,1982	16,2000	07,1976 19,2002 07,2008	04,2008	1998-08-03
CT/AM	Wa/PPmsWa/ PPmc	SWa/ PPmc	Ka/PPk	Sa/PZ	Bc/PZ	Bc/rmp	Bc/PPms	Bc/PZ	Bc/rmp	SEc/PA	Sa/PPm Sc/PPm Sa/PPmc	SWc/ PPms	Bc/PZ
ΔT, °C	38.2	37.3	41.1	32.2	30.4	29.7	27.1	27.5	30.8	34.6	34.6	36.8	56.1

CT – air circulation type, AM – air mass

Table 4. Essential characteristics of atmospheric precipitation at Pozhyzhevska weather station, 1961-2010

Characteristic	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Average RR, mm	76.4	87.3	111.8	103.8	143.5	178.4	181.3	129.8	116.7	105.3	108.4	103.4	1446.1
Maximim RR, mm	72.8	61.3	116.9	49.4	96.8	98.4	80.1	64.1	57.4	73.3	56.3	82.4	116.9
date	02,1962	13,1962	05,2001	21,2005	13,1970	08,1969	26,2008	13,1986	19,2007	29,1998	15,1987	09,2010	2001-03-05
CT	SEc	Wc	Na	NEa	NWc	NEc	Ec	Bc	Ka	Wc	Wa	Bc	Na
AM	PPm	PPm	PPms	PA	PPm	PPms	PPk	mp	PPms	PPm	PPm	PA	PPms

CT – air circulation type, AM – air mass

Table 5. Number of different categories of atmospheric precipitation at Pozhyzhevska weather station, 1961-2010

Characteristic	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	**Year**
RR (≥0,1 mm)	14.9	15.6	16.7	15.4	17.8	18.2	18.1	14.4	13.3	13.1	15.1	16.0	188.6
RR (≥10 mm)	2.0	2.3	3.2	3.3	5.1	6.5	6.2	4.8	4.2	3.6	3.5	3.1	47.8
RR (≥30 mm)	0.1	0.2	0.6	0.4	0.6	1.0	1.1	0.6	0.5	0.5	0.4	0.3	6.3

Table 6. Essential characteristics of snow cover at Pozhyzhevska weather station, 1961-2010

Characteristic	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Mean SD (cm)	22.1	29.2	30.9	18.4	1.1	0.0	.	.	0.1	2.1	7.0	14.2	12.5
SDmax (cm)	85.0	120.7	121.3	134.0	80.0	16.0	.	.	28.0	62.7	93.3	73.3	134.0
Year	1979	1996	2006	1995	1982	1962	.	.	1970	2009	1994	1995	1995
Average number of days with snow cover	30.2	27.8	29.3	18.8	2.8	0.2	.	.	0.4	5.6	16.4	26.5	158.0
Average number of days with SD>10 cm	19.7	19.9	21.0	11.0	0.9	0.1	.	.	0.0	2.1	6.1	13.7	94.6

sidering P index we observe gradual intensification of western air inflow. However, there are not any changes in S index and in particular years predominated south or north inflow of air masses (Fig. 2).

There are found several regularities in mean annual values of essential climate variables and annual values of air circulation indicators. Moderate and intensive cyclonic inflow generates low values of mean and minimum air temperature and increased totals of precipitation. At moderate eastern air inflow low precipitation totals and minimum temperature was found. However, at southern air inflow are observed increased values of air temperature (mean, minimum and maximum) and in years with intensive northern air inflow reduced precipitation totals occurs (Table 7).

Statistical analysis of annual values of climate variables shows that significant changes were noted only for three characteristics of air temperature, three measures of snow cover and two characteristics of precipitation. In air temperature (Fig. 3) significant gradual increase was found for mean values (0.127 °C/10 years), mean minimum (0.225°C/10 years) and absolute maximum (0.323°C per 10 years). Significant increase is also observed in mean annual and maximum annual snow depth (SD – 1.382 cm/10 years and SDmax – 9.153 cm/10 years) as well as in an amount of days with snow cover >10 cm (9.349 days per 10 years) (Fig. 4). In precipitation totals we have found two phases of changes. In the years 1961-1991 they were gradually reduced and in last 20 year RR increased (Fig. 5). Such changes causes that 50-years trend is statistically insignificant. However, significant changes were found for the number of days with precipitation (-8.87 days per 10 years) and in number of heavy rains (>30 mm), +0.68 days/10 years. Determination coefficients varied from 8.25% for TM to 27.5% for RRdays (Table 8).

Changes in selected climate characteristics in particular seasons were also analysed. At Pozhyzhevska in summer the significant increase was observed at TM (0.34°C/10 years), TN (0.35°C/10 years) and TX (0.33°C per 10 years). Significant increase of TX (0.47°C/10 years) was also found for winter. It is worth emphasizing that changes are also significant in case of the number of days with snow depth above 10 cm (SD>10). However precipitation totals and SDdays were not significant in any season. The

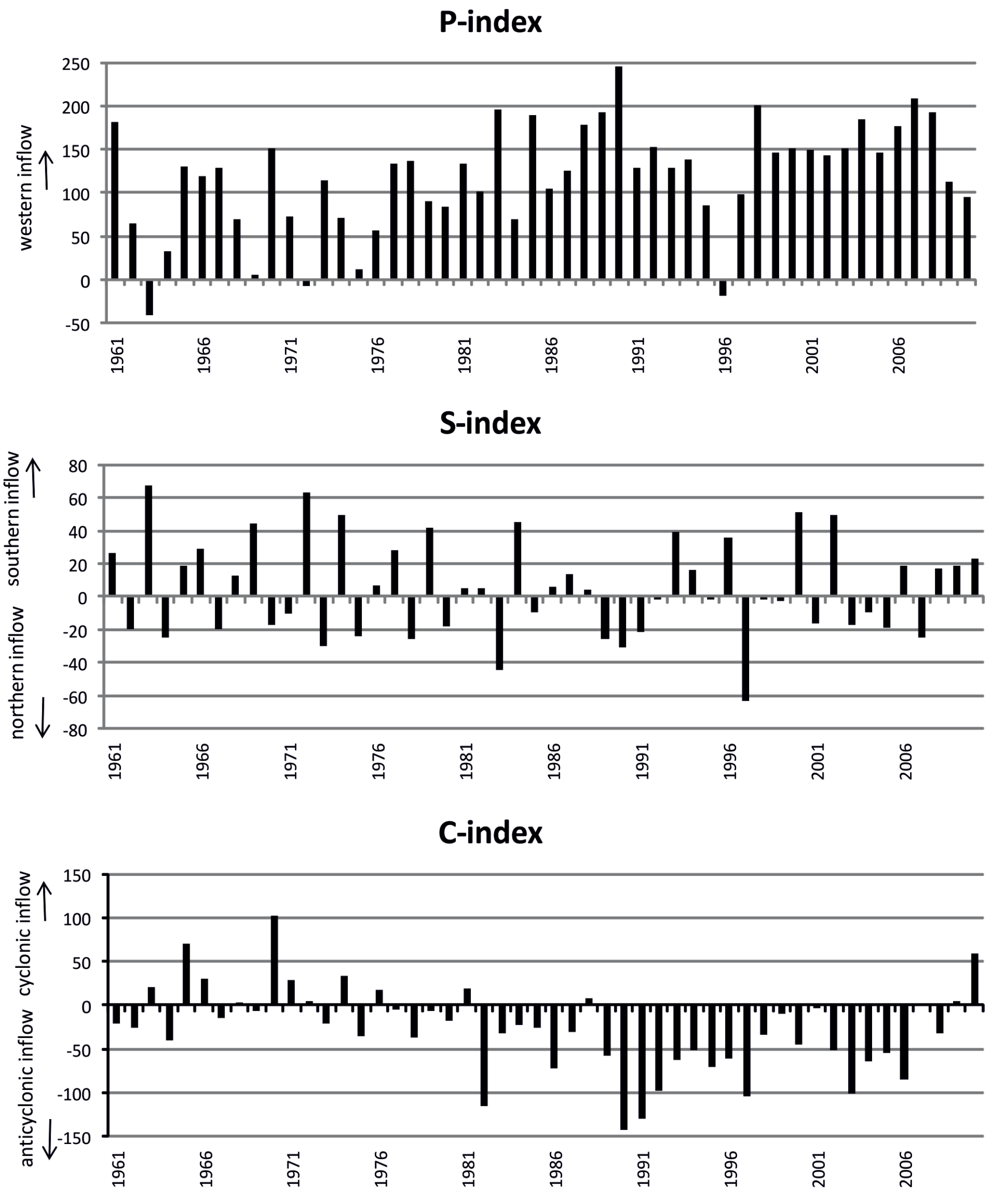

Fig. 2. Annual values of circulation indices, northern Carpathians, 1961-2010

coefficient of determination for air temperature varies from 8.5% (in summer for TX) and reaches even 23.8% (in summer for TM). The trend values of air temperature at summer season were 0.33°C per 10 years for TX (at significance level of 95%), 0.34°C per 10 years for TM (at 95% level) and 0.35°C/10 years for TN (at 90% significance level). Trend in the number of days with snow depth more than 10 cm (SD>10) range from +1.46 cm/10 years in autumn to +4.66 cm/10 years in winter (at 95% level) (Table 9).

One of important climate characteristics are normals of 30-years periods. Usually 1961-1990 and 1981-2010 periods are in use. For Pozhyzhevska weather station the values of temperature normals do not differ significantly. Mean annual air temperature and average yearly maximum temperature differ only of 0.2°C. Average yearly minimum differs of 0.4°C. Slightly greater are differences in precipitation normal. The highest in normal for 1981-2010 and the lowest one – for 50-years period (Table 10).

Table 7. Mean annual values of essential climate variables in different categories of C, P and S indices, Pozhyzhevska, 1961-2010

C index	TM	TN	TX	RR
intensive anticyclonic (C ≤ -75)	3.0	0.5	5.9	1242.6
moderate anticyclonic (C from -74 to -20)	2.9	0.4	5.8	1457.2
neutral (C from -20 to +20)	2.9	0.4	5.9	1515.5
moderate cyclonic (C from 21 to 54)	2.9	0.4	6,1	1524.8
intensive cyclonic (C ≥ 55)	2.6	-0.1	5.7	1843.6
P index	**TM**	**TN**	**TX**	**RR**
moderate eastern (P ≤ -15)	2.6	-0.1	5.8	1281.4
neutral (P from -14 to +14)	3.2	0.7	6.1	1273.2
moderate western (P from 15 do 105)	2.7	0.2	5.7	1484.5
intensive western (P from 106 to 155)	2.9	0.3	5.9	1443.9
very intensive western (P ≥ 156)	3.2	0.7	6.1	1569.1
S index	**TM**	**TN**	**TX**	**RR**
intensive northern (S ≤ -30)	2.9	0.0	5.4	1249.4
moderate northern (S from -15 to -29)	2.8	0.3	5.9	1549.3
neutral (S from-10 to +10)	2.6	0.2	5.5	1449.0
moderate southern (S from 11 to 29)	3.2	0.6	6.3	1626.4
intensive southern (S ≥ 30)	3.0	0.4	5.9	1307.4

Table 8. Annual statistical characteristics of the 50-years changes of different climate variables at Pozhyzhevska, 1961-2010

Variable	r	R^2 (%)	P-Value	10 years trend	Significance level (%)
TM	0.287	8.25	0.043	0.13°C	95
TN	0.357	12.72	0.011	0.22°C	95
TN abs	0.181	3.28	0.280	0.36°C	ns
TX	0.112	1.25	0.439	0.05°C	ns
TX abs	0.294	8.65	0.038	0.32°C	95
TN<-10	-0.140	1.97	0.331	-1.20 days	ns
TX<0	0.140	1.97	0.331	1.34 days	ns
TX-<-10	0.039	0.16	0.785	0.18 days	ns
TX>25	0.219	4.81	0.126	0.18 days	ns
SD	0.361	13.00	0.010	1.38 cm	95
SD max	0.510	25.98	0.000	9.15 cm	99
SD days	0.102	1.05	0.479	1.20 days	ns
SD>10	0.419	17.57	0.002	9.35 days	99
RR	0.133	1.77	0.357	23.72 mm	ns
RR days	-0.524	27.5	0.000	-8.87 days	99
RR>10	0.213	4.53	0.138	1.34 days	ns
RR>30	0.294	8.63	0.038	0.68 days	95

r – correlation coefficient. R^2 – determination coefficient, ns – insignificant

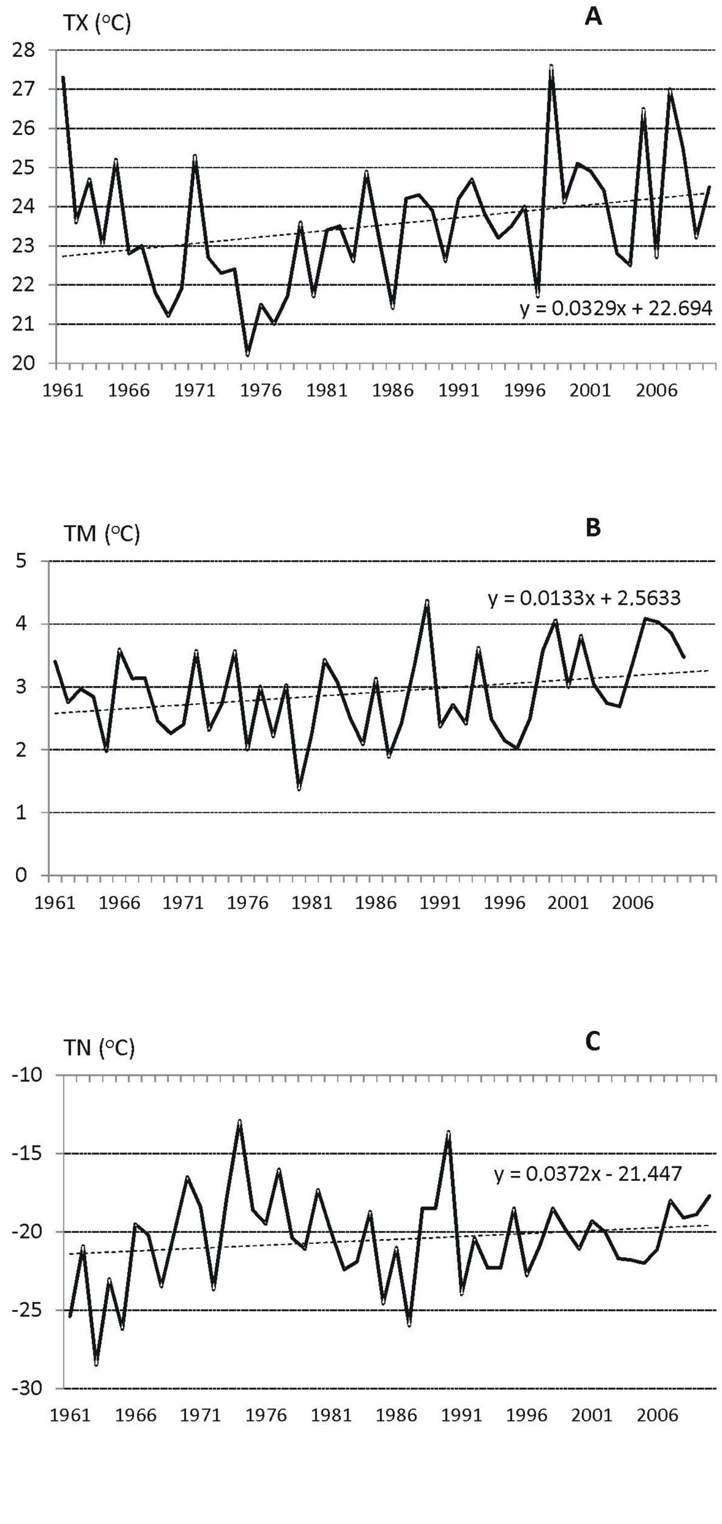

Fig. 3. Annual values of highest maximum (A, TX), mean (B, TM) and lowest minimum (C, TN), Pozhyzhevska, 1961-2010

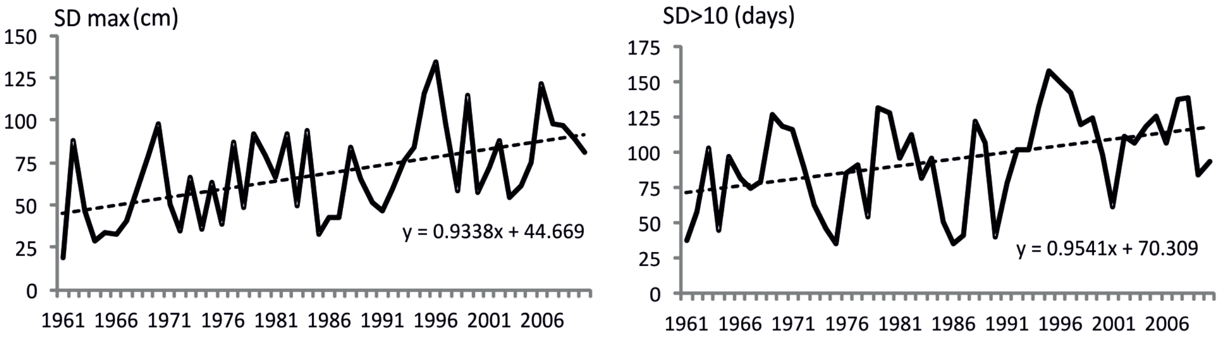

Fig. 4. Annual values of maximum snow cover (SD max) and number of days with snow >10 cm (SD>10), Pozhyzhevska, 1961-2010

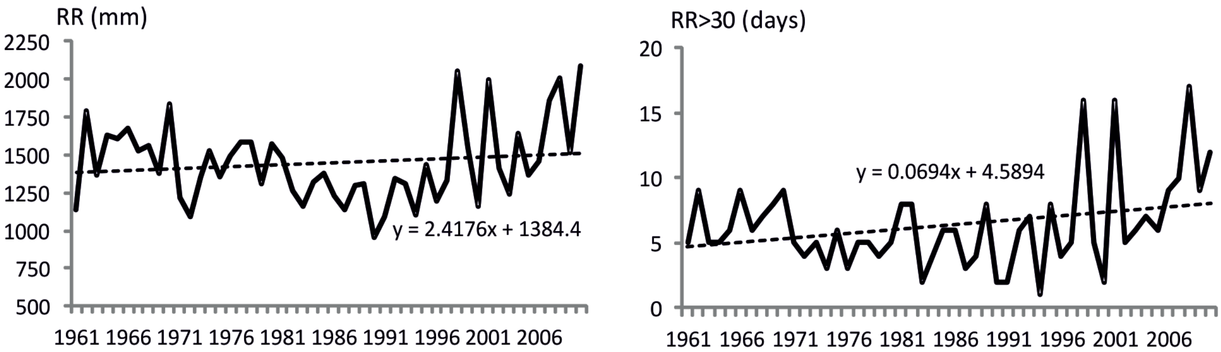

Fig. 5. Annual totals of atmospheric precipitation (RR) and number of days with precipitation >30 mm (RR>30), Pozhyzhevska, 1961-2010

Discussion

Despite the relatively long period of observations there are no studies that characterise contemporary climate of Chornohora and its changes. The research published previously (Matviyiv 2003; Kotarba 2006; Petlin and Shuber 2013; Mukha 2017) do not provide such information, especially for long-term periods. Thus, the present study gives first information on the many-year features of climate and its long-term changes of Chornohora climate.

The annual value of air temperature at Pozhyzhevska is higher than TM observed at Śnieżka and Kasprowy Wierch (due to elevation of stations) and is compared with TM at Hala Gąsienicowa which is located at the similar altitude as Pozhyzhevska. Also the number of days with snow cover at Hala Gąsienicowa and Pozhyzhevska is similar each other (Błażejczyk et al. 2013; Błażejczyk 2019). Regarding precipitation its totals are smaller in Chornohora in comparison to Karkonosze and Tatry what is an effect of the elevations of mountain chains (Migała 2005; Bokwa et al. 2013; Ustrnul et al. 2015; Żmudzka et al. 2015; Błażejczyk 2019).

For Chornohora the change in mean annual temperature is +0.13°C/10 years. Similar trends were found for Tatry (Żmudzka 2009, 2011) and for Karkonosze Mts. (Głowicki 2000; Migała et al 2016). However, air temperature trends calculated by Bokwa et al. (2013) and Błażejczyk (2019) for Tatry and Karkonosze Mts. are greater than in present study. The differences are probably caused by the considered period which in case of the last research was the longest (1951-2015). The changes of TN and TX in Chornohora (0.22°C and 0.05°C, respectively) were similar to trends reported for Karkonosze and Tatry Mts by Głowicki (2000) and by Wibig and Głowicki (2002). However, they are smaller than trends founded by Błażejczyk (2019) for the longest data series.

Table 9. Seasonal statistical characteristics of 50-years changes of TM, TN, TX, RR, SDdays and SD>10, Pozhyzhevska, 1961-2010

Variable	Season	r	R^2 (%)	P-Value	trend/10 years	Significance level (%)
TM	Winter	0.185	3.43	0.1977	0.16°C	ns
	Spring	0.179	2.21	0.3026	0.12°C	ns
	Summer	0.488	23.85	0.0003	0.34°C	99
	Autumn	-0.132	1.74	0.3606	-0.11°C	ns
TN	Winter	0.178	3.19	0.2149	0.36°C	ns
	Spring	0.163	2.67	0.2567	0.42°C	ns
	Summer	0.271	7.35	0.0568	0.35°C	90
	Autumn	-0.016	0.03	0.9102	-0.03°C	ns
TX	Winter	0.362	13.08	0.0099	0.47°C	95
	Spring	0.070	0.49	0.6307	0.10°C	ns
	Summer	0.292	8.53	0.0396	0.33°C	95
	Autumn	-0.082	0.67	0.5707	-0.11°C	ns
RR	Winter	-0.040	0.16	0.7841	-3.02 mm	ns
	Spring	0.202	4.08	0.1598	15.10 mm	ns
	Summer	-0.034	0.12	0.8136	-2.72 mm	ns
	Autumn	0.195	3.79	0.1754	14.33 mm	ns
SDdays	Winter	-0.035	0.12	0.8108	-0.20 days	ns
	Spring	0.070	0.50	0.6272	0.51 days	ns
	Autumn	0.152	2.31	0.2917	1.00 days	ns
SD>10	Winter	0.343	11.79	0.0146	4.66 days	95
	Spring	0.306	9.34	0.0309	3.30 days	95
	Autumn	0.311	9.66	0.0280	1.46 days	95

r – correlation coefficient, R^2 – determination coefficient, ns – insignificant

Table 10. Climate normals for Pozhyzhevska station for different periods

Characteristic	1961-2010	1961-1990	1981-2010
mean TM, °C	2.8	2.8	3.0
average TN, °C	-7.3	-7.5	-7.1
average TX, °C	13.8	13.7	13.9
RR	1404.7	1423.1	1446.1

The long-term, insignificant changes in precipitation totals in Chornohora is +23.7 mm/10 years. In the case of Kasprowy Wierch and Śnieżka RR trends founded by Błażejczyk (2019) are negative (-7.6 mm/10 years and -70.8 mm/10 years, respectively). However, trends founded by that author is statistically insignificant only for Tatras. Extreme precipitation in Chornohora are smaller that reported by Niedźwiedź (2003) for Tatras.

In our research we did not found changes in number of days wits snow cover in Chornohora in contrary to Karkonosze where Urban (2015) reported decrease in snow cover days. Also Falarz (2002) did not found any changes in snow cover in Tatry Mts for the period 1950-1999. However. research of Gądek et al (2016) reported significant decrease in snow cover depths and number of snowy days at Hala Gąsienicowa in years 1991-2015. Significant increase in snow depth (SD, SDmax) and days with SD>10 was studied and observed only at Pozhyzhevska.

The results of present research partially confirm foundings of another research and any differences in trends reported by various authors can be explain by different periods considered in their studies.

Conclusions

The results of research shows that air temperature. precipitation and snow cover characteristics at mountains stations depend mostly of their elevation above sea level. According to altitude air temperature is decreasing and precipitation totals and snow cover is increasing.

It seems that long-term changes in air temperature are in Chornohora smaller then in compared Central European mountain ridges. Reduction of precipitation is observed in western part of the region and increase in snow cover – in its eastern part.

More comparative, detail studies, considering the same period of observation in various mountain ridges, are necessary to find general picture of climate changes in different mountainous ecosystems.

Disclosure statement

No potential conflict of interest was reported by the authors.

Author Contributions

Study design: K.B.; data collection O.S.; statistical analysis: O.S.; result interpretation K.B.; manuscript preparation O.S., K.B.; literature review: O.S.

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